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DEMONSTRATING ACQUISITION OF REAL-TIME THERMAL DATA OVER FIRES UTILIZING UAVS

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ABSTRACT

A disaster mitigation demonstration, designed to integrate remote-piloted aerial platforms, a thermal infrared imaging payload, over-the-horizon (OTH) data telemetry and advanced image geo-rectification technologies was initiated in 2001. Project FiRE incorporates the use of a remotely piloted Uninhabited Aerial Vehicle (UAV), thermal imagery, and over-the-horizon satellite data telemetry to provide geo-corrected data over a controlled burn, to a fire management community in near real-time. The experiment demonstrated the use of a thermal multi-spectral scanner, integrated on a large payload capacity UAV, distributing data over-the-horizon via satellite communication telemetry equipment, and precision geo-rectification of the resultant data on the ground for data distribution to the Internet. The use of the UAV allowed remote-piloted flight (thereby reducing the potential for loss of human life during hazardous missions), and the ability to "linger and stare" over the fire for extended periods of time (beyond the capabilities of human-pilot endurance). Improved bit-rate capacity telemetry capabilities increased the amount, structure, and information content of the image data relayed to the ground. The integration of precision navigation instrumentation allowed improved accuracies in geo-rectification of the resultant imagery, easing data ingestion and overlay in a GIS framework. We focus on these technological advances and demonstrate how these emerging technologies can be readily integrated to support disaster mitigation and monitoring strategies regionally and nationally.

INTRODUCTION

NASA, tasked with developing UAV utility in the aerospace and research community, has embarked on an ambitious program to push the technological "envelop" of UAV use in research and applications. The NASA program, ERAST (Environmental Research Aircraft and Sensor Technology) seeks to develop and flight-demonstrate remotely piloted aircraft for cost-effective science missions. Further goals are to demonstrate the utility of UAV's in situations that would be deemed most appropriate for the technology. These parallel applications efforts seek to "concept-prove" UAV's as data gathering platforms to agencies and public entities in need of such technology. Since the mission of UAV's are to provide an unmanned airborne platform in situations that would put a pilot at risk, the use of these aircraft in data gathering over wildfires is enticing (Brass *et al.*, 2001).

NASA-Ames Research Center (Moffett Field, California) is leading the ERAST applications activities and completed a demonstration of the UAV as a wildfire remote sensing platform; gathering thermal data over fires and relaying that information through a satellite communications telemetry system in real-time to fire management personnel on the ground. The FiRE (First Response Experiment) experiment demonstrated the combined use of a thermal multi-spectral scanner, integrated on a large payload capacity UAV, a satellite image data telemetry system, near-real-time image geo-rectification, and rapid Internet data dissemination to disaster managers. The FiRE demonstration was a technology follow-on activity to the successful WILDFIRE experiment flown aboard a manned platform over a fire in 1997 (Ambrosia *et al.*, 1998). The FiRE demonstration occurred in El Mirage, California in September 2001 and involved imaging a controlled burn and relaying the imagery in near real time. This paper describes the results of that demonstration and provides the framework for future endeavors with long-duration UAV's as fire imaging payload platforms.

The FiRE demonstration was a close collaboration among federal and state agencies and private industry. General Atomics Aeronautical Systems Inc. (GA-ASI) developed, built and flew the ALTUS® II UAV airborne platform (Figure 1), while NASA-Ames supplied the Airborne Infrared Disaster Assessment System (AIRDAS) thermal infrared scanner for integration as the imaging payload on the ALTUS® II.

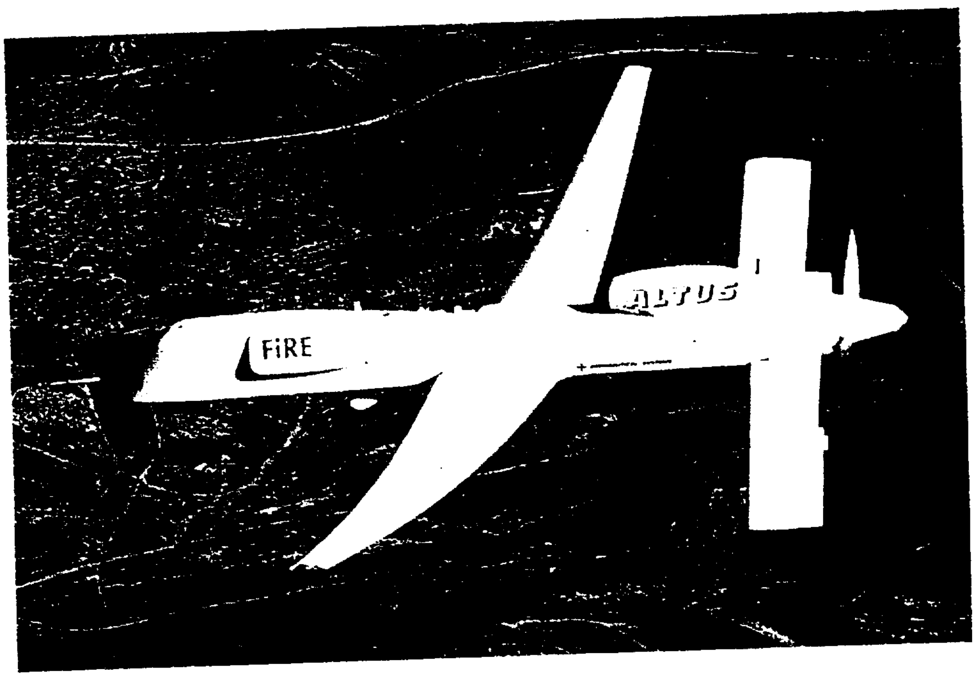

Figure 1. The ALTUS® II UAV in flight during the FiRE demonstration mission, September 2001. The payload (AIRDAS scanner) is located in the nose of the platform.

Full system integrations (as well as the experimentation flight) were performed at the GA-ASI Flight Operation Facility in El Mirage, (San Bernardino County) California. The data telemetry system, a modified NERA World Communicator M4 portable satellite telephone terminal and antenna offering ISDN functionality and pure digital interface, was provided by Remote Satellite Systems, Inc. of Santa Rosa, California. The telemetry system was modified for remote aircraft operations by NASA-Ames and integrated into the fuselage fairing of the ALTUS® II by GA-ASI. Terra-Mar Resource Information Services of Mountain Ranch, California, performed image geo-rectification in near real time. The U.S. Forest Service and the State of California Resources Agency (disaster managers) participated as technology reviewers and provided feedback on the resultant fire image data sets.

The goals of the demonstration were to:

1. Integrate a thermal imaging payload and telemetry equipment on a high performance UAV.
2. Operate the payload remotely from a ground station.
3. Telemeter payload data from the UAV to a communications satellite and over-the-horizon (OTH) to a computer server.
4. Provide automated geo-rectification of the data.
5. Globally disseminate that data to the Internet and disaster managers.

The overarching objective was to provide the right information to the right people, at the right time. Based on these criteria, the FiRE team proposed delivery of a fully geo-rectified image file within 15 minutes of acquisition aboard the UAV.

SYSTEMS DESCRIPTION

ALTUS® II Description

The ALTUS® II was developed by GA-ASI under the NASA AeroSpace Enterprise, ERAST program as a scientific research and applications platform. The specifications of the platform are shown in Table 1.

Table 1. General Atomics – Aeronautical Systems, Inc. (GA-ASI) ALTUS® II UAV system specifications.

Dimensions	Wing Span 55.3 ft.; Wing Area 132 sq. ft.; Length 23.6 ft.; Height 9.8 ft.
Weights	Max Fuel Wt. 550 lb; Payload Wt. 330 lb.; Max GTOW 2,150 lbs.
Propulsion/Fuel	Rotax 914-2T Dual Turbo; liquid-cooled four cylinders. Rated 100 HP @ 52,000 ft.
Performance	Max Altitude 65,000 ft.; Endurance: 8 Hours (at 60K), 18 Hours (at 30K), 24 Hours (at 25K); Max Speed 100 KIAS, Cruise/Loiter Speed 65 KIAS
Payload Specs	Size: 58"L x 26"H x 27"W, (Adaptable); Max Wt. 300 lbs., Payload Power Available 1.8 kW
Shipping Size	319"L x 48"H x 57"W
Navigation	Litton LN-100G INS/GPS (P-Code GPS)
Avionics	GA-ASI PCM, C-Band Line-Of-Sight RF, adaptable for Over-The-Horizon Operations.
FTS	GA-ASI Rocket deployed parachute and NASA Flight Termination System
Landing Gear	Normal tricycle type retractable landing gear.

For avionics controls, the UAV communicates with the remote pilot and payload operator via a C-band line-of-sight radio frequency (RF). The aircraft is also adaptable for over-the-horizon (OTH) operations via a satellite communications link. This command and control (C^2) link is separate from the data telemetry link, and is used strictly for flight and instrument operations. Remotely piloted flight operations for the ALTUS® II UAV platform are performed on the ground at the GA-ASI Ground Station. The ALTUS® II, and all GA-ASI aircraft are controlled by a portable common solid-state digital ground control station (GCS) through a C-Band line-of-sight (LOS) data link. The GCS is capable of direct control of the UAV and passing real-time payload data at ranges up to 150 NM. In addition to the LOS link, a high data rate Ku-Band satellite data link for routine over-the-horizon operations is available and has been used by the military and will be expanded for civilian use shortly.

AIRDAS Thermal Imaging Payload

The AIRDAS thermal scanner was flown on the ALTUS® II for the FiRE demonstration. The AIRDAS is a four-channel line-scan instrument designed for airborne imaging of wildland fires and other natural and man-induced disasters (Table 2)(Ambrosia *et al.*, 1994).

Table 2. AIRDAS System configuration and characteristics for payload operations aboard GA-ASI ALTUS® II UAV.

System Composition:	Texas Instruments© RS-25 thermal line-scanner optics; Non-linear detector pre-amplifiers; Sixteen-bit Digitizer; Dichroic filters for spectral channel separation.
Control Computer:	Pentium© I Pro 233 MHz system; On-Board ETHERNET; SCSI; High-speed serial ports running QNX OS; Kingston© 18.0 GB removable hard drive storage device; Integrated Motorola© Chassis-Mounted GPS Receiver; Kennedy© 2-axis gyroscope
Weight and Power:	Scan Head: 95 lbs.; Control computer and peripherals: 70 lbs.; Requires 28V DC @ 20 amps
Sensor Parameters:	FOV: 108 deg.; IFOV: 2.62 milliradians; Scan Rate: 4-23 scans/sec.; Digitized Swath Width: 720 pixels; Spatial Resolution: 26 ft. (8m) at 10K ft.
Spectral Configuration:	Channel 1: 0.64 – 0.71 μm 2: 1.57 – 1.70 μm 3: 3.75 – 4.05 μm (narrowing filter available) 4: 5.50 – 13.0 μm (narrowing filter available)

The AIRDAS has been laboratory-calibrated to accurately resolve fire intensities up to 873°K (600°C). Each of the specific AIRDAS bands provides useful information for fire analysis. The visible band 1 is suitable for monitoring smoke plumes as well as distinguishing surface cultural and vegetative features not obscured by smoke or clouds. Band 2 is suitable for analysis of vegetative composition, as well as very hot fire fronts, while still penetrating most associated smoke plumes. Band 2 is sensitive to fires and hot spots at temperatures above 573°K (300°C)(Riggan *et al*., 1993). Band 3 (mid-infrared thermal) is specifically designed for estimating high temperature conditions. Band 4 is designed to collect thermal data on earth ambient temperatures and on the lower temperature soil heating conditions behind fire fronts, as well as the minute temperature differences in pre-heating conditions (Ambrosia and Brass, 1988).

The AIRDAS contains an integrated Motorola® chassis-mounted Global Positioning System (GPS) unit, and a Kennedy® two-axis gyro. The GPS data is integrated into the scanner output and delivers encoded location information on aircraft position to the header file for each flight segment (scan line). The two-axis gyro sends encoded information on pitch and roll to the control system in order to allow for post-flight correction. A magnetic compass assists in determining heading, allowing for geometric correction. The barometric altimeter data is also incorporated in the header. The system accommodates additional serial interfaces to integrate other avionics navigation systems on airframes that acquire such information.

Significant software and hardware modifications were made to the AIRDAS system to allow UAV remote payload control from the GCS. These modifications included streaming the system health data from the on-board computer to the payload operator's computer on the ground. The AIRDAS fit easily into the payload bay of the ALTUS® II, but received minor software modifications to optimize remote instrument operations (Figure 2).

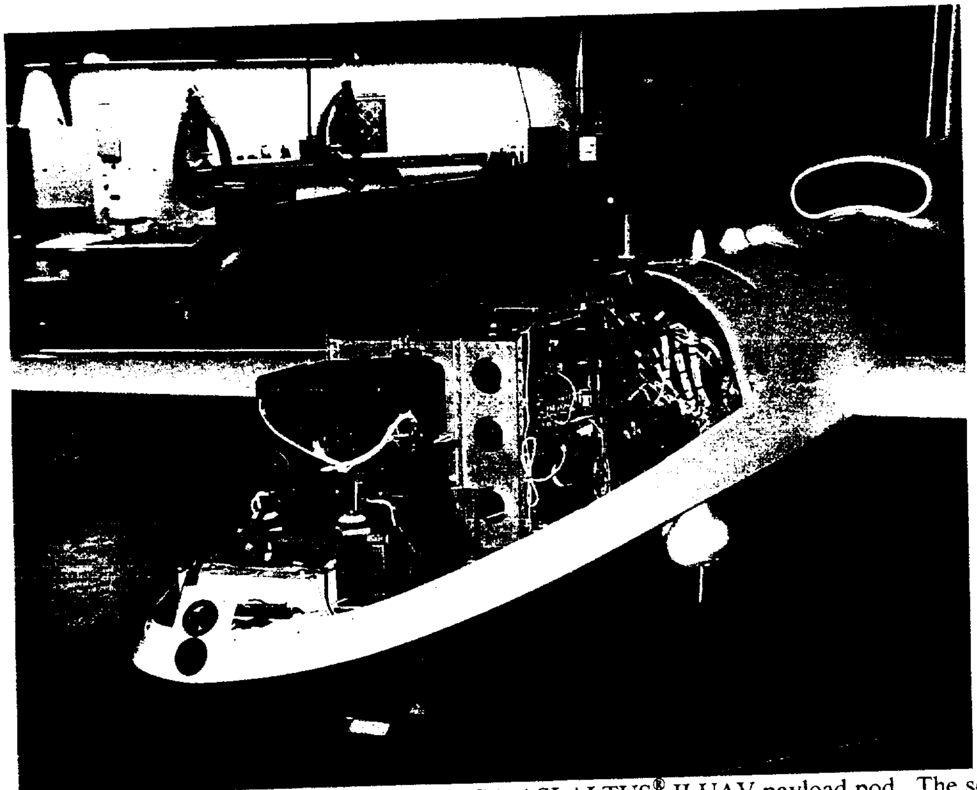

Figure 2. The AIRDAS system integrated into the GA-ASI ALTUS® II UAV payload pod. The scan head is located in the forward portion of the payload bay above the open port, with the computer control rack immediately aft of the head electronics. The forward looking video camera can be seen in the nose of the UAV, while the command and control communications antenna is located on the belly of the fuselage, aft of the payload bay and ports.

Remote Operations of Payload

The AIRDAS payload operator and all system controls were located in the command and control trailer (Figure 3). This allowed direct communication with the pilots and flight engineer and access to the same forward and downward-looking video data. A downward-looking video camera, placed in the nose of the ALTUS® II, provided real-time coverage information of the potential target areas. By incorporating this camera view with the streaming GPS and moving map display, the payload operator was able to ascertain the UAV position and select the optimum AIRDAS data capture time. When the ALTUS® II was over the controlled burn site, the instrument operator in the GCS initiated the AIRDAS data capture and saved the resultant thermal multispectral scene and an associated platform / payload navigation file. The AIRDAS image data were saved as *jpg*-compressed files of 720 x 640 pixels x 3 bands (approximately 100 Kb). The associated "navigation" file composed of sensor profile and attitude data (pitch, roll, yaw, time, heading, etc.) was also captured and telemetered to a ground receiving location along with the image file. The associated navigation files were 9 Kbs. The "navigation" files were necessary for AIRDAS image geo-rectification.

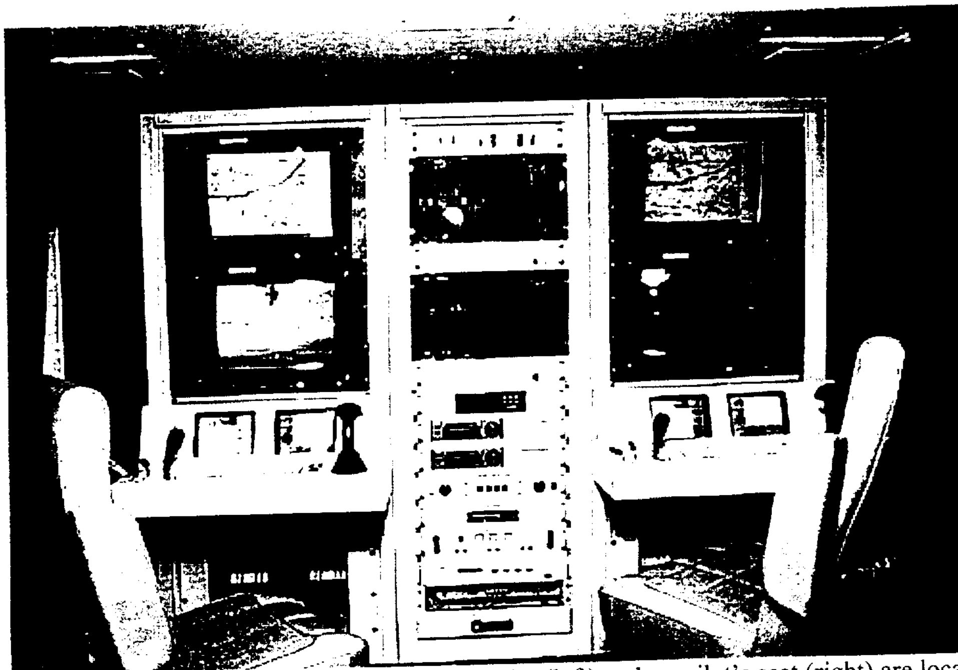

Figure 3. The GA-ASI Ground Control Station. The pilot (left) and co-pilot's seat (right) are located in the GCS mobile trailer. Communications link between the pilot and the UAV are provided by a C-band command and control data link or Ku-band, OTH link. The operators utilize a moving map display (upper left) and a UAV-mounted, forward-looking video camera display (lower left), in conjunction with attitude and navigation information (lower right) to maintain the appropriate flight profile.

Airborne Data Telemetry System

The data telemetry system was derived from the NERA mobile handheld system that communicates through the INMARSAT series of geo-stationary satellites. The INMARSAT system currently operates at 64Kbs, sufficient for the FiRE project data telemetry activities. The AIRDAS scene data and navigation file were sent from the AIRDAS control computer to the NERA system onboard the UAV. Data were telemetered through a pair of phased array antennas mounted into the skin of the ALTUS® II fuselage, pre-positioned (in elevation) to acquire signal lock with an appropriate INMARSAT geo-stationary communications satellite (NERA, 2001) (Figure 4). For the FiRE demonstration, both the Atlantic Operating Region – West (AOR-W) satellite located at 54° West longitude over the equator and the Pacific Operating Region (POR) satellite at 178° East longitude at the equator were used. The data were then telemetered via a File Transfer Protocol (FTP) login to a file server for INTERNET distribution. Individual image file transfer procedures required approximately two minutes for full data delivery.

Geo-Rectification and Data Distribution

AIRDAS data and the associated navigation data file, transmitted via from the ALTUS® II UAV through INMARSAT were received at a workstation server at NASA-Ames Research Center, Moffett Field, California. The data were accessible by fire managers immediately at the UAV FiRE website (**http://geo.arc.nasa.gov/sge/UAVFiRE/**). At the same time, the two data files were used to create the geo-rectified data sets using the Terra Mar Data Acquisition Control System (DACS) software package. The DACS system utilizes the aircraft / payload attitude information and a sensor model to geo-rectify the data (Wong, 1980). If terrain data is available (Digital Elevation Model (DEM) or Shuttle Radar Topographic Mapping (SRTM) data), the geo-rectification improves greatly and the resultant data sets can be easily draped over other registered files such as maps, etc, in a GIS or used to create 3-D perspectives of the fire.

Figure 4. NERA Telecommunications M4 WorldCommunicator® portable satellite terminal phased array antenna. The antenna communicates with the INMARSAT series of communications satellites. The antennas (one on each side of the UAV fuselage) were oriented at an appropriate intercept angle for satellite communications.

FiRE DEMONSTRATION

The FiRE demonstration mission occurred on 6 September 2001 at the GA-ASI Flight Operations Facility in El Mirage, California. Immediately prior to the ALTUS® II launch, the controlled burn was ignited adjacent to the aircraft runway. The mission plan was for the ALTUS® II to make numerous passes over the controlled burn during a one-hour allocated flight and burn time. The controlled burn was ignited and ALTUS® II was launched (Figure 5). After attaining planned data collection altitude (6000 feet MSL; ~3100 feet AGL), the ALTUS® II flew "racetrack" patterns in an east / west orientation over the controlled burn. A total of five data collection passes were made over the fire and data were relayed to the ground receiving station for geo-rectification. At the same time, fire managers were able to view the data via a remote login to the NASA-Ames server, with the data displayed on a theater projection system at the GA-ASI El Mirage Flight Facility. The geo-corrected images were sent back to the server and available within ten (10) minutes of being collected (Figures 6, 7 and 8).

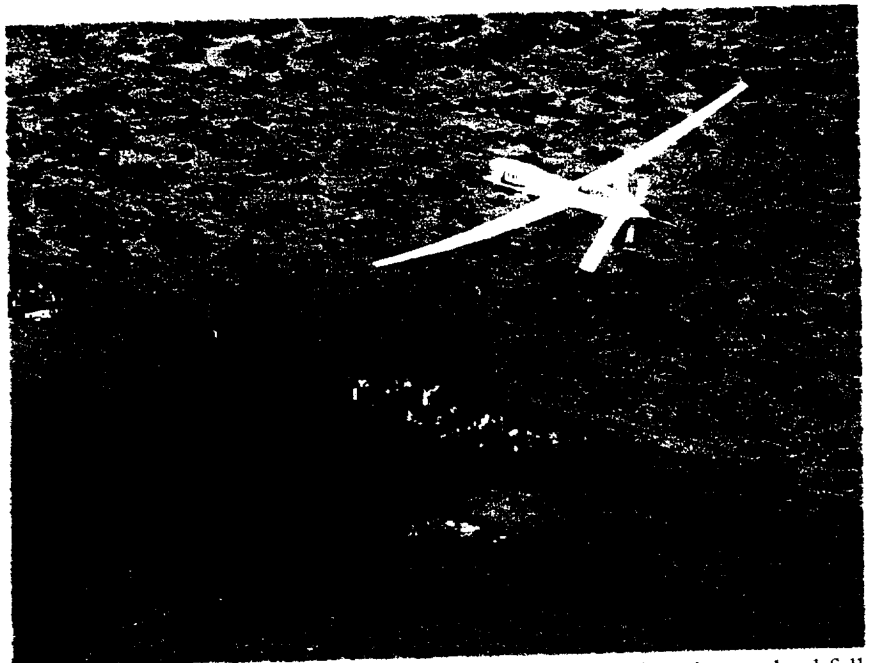

Figure 5. The ALTUS® II UAV containing the NASA-Ames AIRDAS imaging payload following takeoff from the GA-ASI Flight Operations Facility. Flames and smoke from the controlled burn, ignited earlier, can be seen below the aircraft. The aircraft climbed to altitude and collected data over the burn from 6000 feet (1830 meters) MSL (~3100 ft AGL).

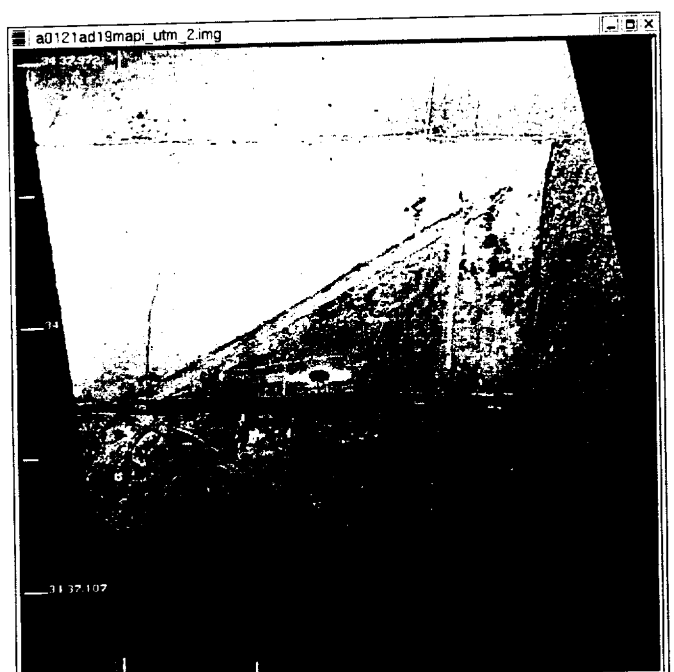

Figure 6. AIRDAS single band thermal data (band 3, 3.60-5.50μm) acquired from the GA-ASI ALTUS® II UAV flying at 6000 feet MSL (~3100 ft AGL) over the FiRE controlled burn at El Mirage, California on 6 September 2001. In this fully geo-rectified scene (note the latitude / longitude tics along image margins), the fire (in red for reference) can be seen immediately north of the cooler runway. These scenes were collected, telemetered through the NERA antenna to INMARSAT, sent over the horizon (OTH) to NASA-Ames, geo-rectified, and redistributed to the web in under 10 minutes of collection

Figure 7. AIRDAS data collected from the GA-ASI ALTUS® II UAV flying at 6000 feet MSL (~3100 ft AGL) over the FiRE controlled burn at El Mirage, California on 6 September 2001 at 8:47 AM (PST). The small fire can be seen in the cleared area adjacent to the runway (bright yellow). This scene was the first data set telemetered to the ground station and is not geo-rectified. Total "collection-to-distribution" time was approximately three minutes.

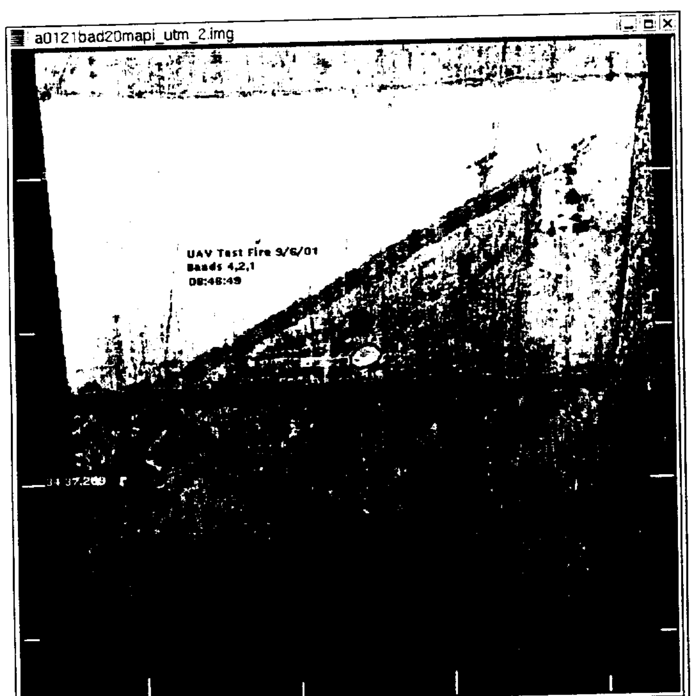

Figure 8. AIRDAS data collected from the GA-ASI ALTUS® II UAV flying at 6000 feet MSL (~3100 ft AGL) over the FiRE controlled burn at El Mirage, California on 6 September 2001 at 8:47 AM (PST). The small fire can be seen in the circled area adjacent to the runway. This scene is a spatially- and geometrically-rectified dataset of Figure 7. Lat/Long tic marks (visible around the edges of the image) were automatically inserted for orientation purposes. The total collection, telemetry, geo-rectification, and data distribution time was approximately ten minutes.

The ALTUS® II completed the FiRE mission data collection and the aircraft landed at 9:30 AM (PST) and was available for viewing by the disaster managers following system and payload shutdown. Greatly exceeding our expectations of one hour for full data dissemination, the ALTUS® II UAV had launched, attained altitude, made five passes over a controlled burn, AIRDAS payload data were telemetered from the UAV to INMARSAT over the horizon (>400 miles) to NASA-Ames, data were geo-rectified, and distributed to the World Wide Web (WWW) and were available to disaster managers around the globe

RESULTS

The FiRE project successfully demonstrated the potential for utilizing UAVs for real time disaster management remote sensing data gathering. The capability of UAVs to safely acquire and report data during hazardous conditions greatly enhances the disaster management community's ability to monitor and mitigate a broad range of disasters. The development and refinement of remote payload operations enhances the use of those payloads on UAVs and other platforms where weight or safety precludes the use of an on-board systems engineer. The rapid development of satellite communications (telemetry) played a significant role in the FiRE demonstration. The ability to telemeter accurate, multispectral imagery to any location in the world frees the disaster manager from being "on-site" at the event. Data distribution can therefore be handled at an appropriate disaster facility, allowing multiple events throughout the continent to be flown, collected, and distributed without the need for multiple ground stations and support crew to retrieve the data. Individual fire event data can be distributed to the responsible on-site management team. With rapidly increasing data-bit rates, large, multi-band data streams can easily be telemetered from any aircraft to anywhere on the globe. Our success at integrating telemetry equipment on the ALTUS® II UAV platform, and the potential to integrate new, tracking antenna systems, will greatly advance the field of rapid data delivery. With an increasing-bit-rate / decreasing-cost ratio, the next challenge will not be in data delivery, but in the ability to interpret all the information relayed to the manager and to make rapid, informed decisions during a major disaster such as a wildfire. Improvements to the image quality of the delivered product will be foremost in the next phase of these activities. The disaster managers and GIS specialists will have to play a key role in defining the variables they need to make more informed decisions during a disaster event.

The GA-ASI ALTUS® II UAV proved to be a capable platform for this disaster support mission. The uniqueness of remotely piloted operations facilitates hazardous operations during critical data gathering conditions. The capability of UAV's to safely acquire and deliver data during hazardous missions greatly enhances the disaster management community's ability to monitor and mitigate a broad range of disasters. The development and refinement of remote payload operations enhances the use of those payloads on UAV's and other platforms where weight or safety precludes the use of an on-board systems engineer. With the ability to switch out pilots easily, the aircraft can remain on-station over a disaster event such as a fire for extended periods of time. This becomes critical in long duration missions, or where monotonous, long-term data collection missions would stress an aircraft pilot. A UAV operates very efficiently within the airspace of hazardous fire conditions (unstable air, large obscuring smoke plumes, and possible rugged terrain conditions); safety of a pilot operating within that same airspace is at risk under those conditions.

CONCLUDING REMARKS

What Does The Future Hold?
The FiRE project team is focused on the further advancements of UAV, payload, telemetry, and information processing for disaster management. The next phase of that research, development, and demonstration will involve the use of a GA-ASI ALTAIR® UAV.

The ALTAIR® is a scientific variant of the GA-ASI PREDATOR B® UAV for use by NASA and other organizations. The ALTAIR® has more than an 750 pound (340 kg) internal payload weight capacity, an endurance of 32 hours (with 700 lb payload), a cruise airspeed of 151 KIAS, an operating altitude above 50,000 feet (15,244 meters) MSL and a range of over 4000 miles (6437 km). The ALTAIR® also employs

OTH command and control via a high data rate (500 Kbs) commercial Ku-band satellite (SATMEX 5) communications datalink system (GA-ASI ALTAIR Experimenter's Handbook, 2001).

The FiRE project team is planning a large-scale demonstration of enhanced disaster management capabilities using the ALTAIR® platform in 2003. The ALTAIR-FiRE project will demonstrate 24-hour coverage of fires throughout the Western United States. This long-duration mission will allow a fire management organization to request multiple AIRDAS thermal IR digital data acquisitions over numerous fires spread throughout an area stretching from Mexico to Canada and the Pacific Ocean to Colorado (Figure 9). The >4000 nautical miles (>6437 km) endurance of the ALTAIR will allow lingering over many of these potential fire events. Data will be transmitted via the aforementioned high data rate (500 Kbs) commercial Ku-band satellite (SATMEX 5) communications datalink system to a fire data management facility. All data will be geo-rectified in near real time and GIS-compatible. This long-duration, large area coverage demonstration mission will exceed the capabilities currently employed to capture tactical fires data over large regions.

The disaster management community is on the cusp of a great technological leap forward, enabled by advancements in airborne platforms (particularly UAVs), sensor and imaging systems, telemetry, information processing and product delivery. The authors are committed to assisting and enhancing the development of these supporting technologies for use by the disaster management community.

Figure 9. The ALTAIR platform shown during a potential long-duration mission, collecting thermal payload image data over fires throughout the Western U.S. The platform is capable of sustained missions greater than 24-hours in length and over 4500 nm endurance.

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DISCLAIMER

The use of product or trade names in this document does not represent endorsement by the U.S. Government or its agents; the product and trade names are included for information purposes only.

REFERENCES

Ambrosia, V.G and J.A. Brass, (1988). Thermal Analysis of Wildfires and Effects on Global Ecosystem Cycling. Geocarto International, 3(1): 29-39.

Ambrosia, V.G., J.A. Brass, J.B. Allen, E.A. Hildum and R.G. Higgins (1994). AIRDAS, Development Of A Unique Four Channel Scanner For Natural Disaster Assessment. Proceedings of the First International Airborne Remote Sensing Conference, 11-15 September, Strasbourg, France, Vol. II, pp 129-141.

Ambrosia, V.G., S.W. Buechel, J.A. Brass, J.R. Peterson, R.H. Davies, R.J. Kane and S. Spain (1998). An Integration of Remote Sensing, GIS, and Information Distribution for Wildfire Detection and Management, Photogrammetric Engineering and Remote Sensing, 64(10): 977-985.

Brass, J.A., V.G. Ambrosia, R.S. Dann, R.G. Higgins, E. Hildum, J. McIntire, P.J. Riggan, S. Schoenung, R. Slye, D.V. Sullivan, S. Tolley, R. Vogler, S. Wegener (2001). First Response Experiment (FiRE) Using An Uninhabited Aerial Vehicle (UAV), Proceedings of 5th International Airborne Remote Sensing Conference, 17-20 September, San Francisco, California, CD paper no. 56, pp 1-9.

General Atomics Aeronautical Systems, Inc. (2001). ALTAIR Experimenter's Handbook, Publication #ASI-00194C, pp. i-F6.

NERA Website (2001). URL: http://www.nera.no/index.html.

Riggan, P.J., J.A. Brass and R.N. Lockwood (1993). Assessing Fire Emissions From Tropical Savanna and Forests of Central Brazil. Photogrammetric Engineering and Remote Sensing, 59(6): 1009-1015.

Wong, K.W. (1980). Basic Mathematics of Photogrammetry. Manual of Photogrammetry, ASPRS, pp. 50-51.